

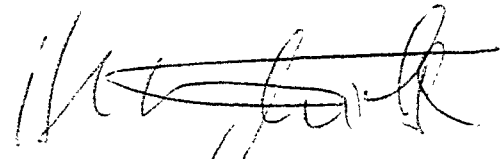


IP7_038779

THIELSCH ENGINEERING, INC.

195 Frances Avenue
Cranston, Rhode Island 02910-2211

**METALLURGICAL EXAMINATION OF
STRESS CORROSION CRACKING
IN BOTTOM ASH SEAL CURTAIN SECTION
UNIT NO. 2
INTERMOUNTAIN GENERATING STATION
INTERMOUNTAIN POWER COMPANY
DELTA, UTAH**



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Susan Freeman

March 3, 1993

Report No. 5455

IP7_038780

INTRODUCTION

A small section of the bottom ash seal curtain was removed from Unit No. 2 of the Intermountain Generating Station and provided to Thielsch Engineering for examination. The seal curtain section had exhibited visual evidence of cracking during routine inspection.

Thielsch Engineering, Inc. was asked to perform a failure analysis of the section received.

BACKGROUND INFORMATION

The seal curtain was fabricated from corrugated stainless steel sheet. Cracking was identified in the seal curtain during shutdown.

The purpose of the seal curtain is to provide a pressure seal during operation allowing the boiler to expand downward freely. The seal curtain hangs from the waterwall header and is suspended into a "recycled ash water" filled trough. This assembly is a portion of the bottom ash handling system.

The unit has been in operation since 1987 for a total of 40,000 hours. The cracking was first noted in November of 1992, and was predominantly identified 4 to 6 inches above the trough water line.

Maximum operating temperatures of the seal curtain were recorded at 500°F to 600°F. Some temperature fluctuations would be expected. The "non-submerged" portion of the curtain would be exposed to reflect radiant heat from the boiler. Appendix A illustrates the temperature gradient of the bottom ash seal curtain during normal operation. At the area of cracking, temperatures typically ranged from 144°F to 156°F.

The seal curtain material is exposed to recycled ash water. Scaling at the water line was also noted. Appendix B identifies the chemistry of the recycled ash water.

LABORATORY EXAMINATION

Visual Examination

A visual examination of the as-received materials was performed. Fig. 1 shows an engineering drawing illustrating the location of the seal curtain and its relative location to the remainder of the boiler components. Photographs provided by plant personnel are presented in Figs. 2 through 4 depicting the Unit No. 2 seal curtain cracking. Cracking was observed in the vertical and horizontal directions.

Fig. 5 illustrates initial cracking observed near the Unit No. 1 waterwall header (bottom photograph). A view of the boiler side of the seal curtain is provided. The top photograph shows an overall view of the cracking observed.

A small semicircular plug sample was removed from the seal curtain. The section received is shown in Fig. 6. The two sections were randomly identified as sections Nos. 1 and 2.

The fracture surfaces of sections Nos. 1 and 2 are shown in Fig. 7. Corrosion product covered the fracture surfaces. These areas were examined analytically for corrosive deposits and for fracture features.

Nondestructive Testing

Radiographic examination was performed on the seal sections provided to further evaluate the extent of cracking. Fig. 8 shows a photographic print of the results. Evidence of secondary cracking was observed.

Metallurgical Examination

A metallurgical examination was performed to evaluate the metallurgical condition of the material and to determine the extent of cracking. Cross section "A-A", shown in Fig. 9, was mounted in bakelite, polished and etched for metallurgical evaluation. Rockwell B hardness determinations were performed at the locations indicated. The corresponding Brinell hardness values ranged from 191 BHN to 203 BHN.

A photomacrograph (magnification 10X) of location "A₂" is provided in Fig. 10. Stress corrosion cracking was evident through the wall thickness of the material. The total wall thickness measured 0.200". Additional areas were selected for examination to verify the cracking mechanism.

Fig. 11 illustrates the microstructure at location "A₃".

The microstructure consisted of austenitic grains with intergranular and transgranular cracking initiating on the internal surface. Extensive branch cracking was evident in the microstructure.

Location "A₄" is shown in Fig. 12. Additional views of the branch cracking were observed. Scale was evident throughout the crack surfaces. Secondary crack initiation was also apparent on the internal diameter.

The crack tips also showed scale product at location "A₅", Fig. 13. The presence of scale in the crack indicates an environmentally induced cracking mechanism. The microstructure consisted of austenitic stainless steel grains.

Analytical Testing

A crack surface was opened to analyze the fracture surface, Fig. 14. The fractographic analysis showed intergranular cracking typical of stress corrosion cracking in austenitic stainless steel.

Energy Dispersive Spectroscopy (EDS) was also performed on the crack surface. Location B, identified in Fig. 6, shows the corrosion product analyzed by Energy Dispersive Spectroscopy (EDS). The results of the analysis are provided in Fig. 15. The primary contaminant was identified as sulfur (present as sulfates). Calcium, sodium, silicon, oxygen and chlorine (chlorides) were also present at this location. The remaining elements represent the base metal.

Location C is also identified in Fig. 6. Heavy surface scale was observed. The Energy Dispersive Spectral (EDS) plot is provided in Fig. 16. High levels of sulfur, chlorine, silicon, oxygen, calcium and potassium were detected. Iron, chromium and nickel represent the base metal.

Locations D and E on the fracture surface, identified in Fig. 7, were also examined. The Energy Dispersive Spectral (EDS) plots of the fracture surface deposits are provided in Figs. 17 and 18. Very high levels of sulfur and chlorine were detected on the fracture surface. These contaminants are highly corrosive to austenitic stainless steels materials.

An analysis of the scale deposits in the crack penetrations was also performed. These areas are identified as locations F and G in Figs. 11 and 12 respectively. The analysis

showed that the scale contaminant was primarily composed of a sulfate based corrosion product. Lesser amounts of chlorides were also detected in the scale.

Chemical Analysis

A chemical analysis was performed using both Optical Emission Spectroscopy (OES) and Leco Carbon Sulfur detection method. The results are shown below:

<u>Element</u>	<u>Seal Curtain</u>	<u>AISI 316 Stainless Steel</u>
C	0.06%	0.08%, max.
Cr	17.30	16.00-18.00
Ni	10.22	10.00-14.00
Mn	1.39	2.00, max.
Si	0.44	1.00, max.
P	0.023	0.045, max.
S	0.034	0.030, max.
Mo	2.12	2.00-3.00

The results show the material complies with AISI Specification 316 stainless steel, with the exception of the sulfur content. The seal trough material was specified as AISI 316L stainless steel material, which has a lower carbon content. The "L" grade material is often specified for welding purposes.

DISCUSSION

The section of seal curtain received showed characteristics of stress corrosion cracking. Austenitic grades of stainless steel are highly susceptible to stress corrosion cracking in the presence of chlorides. Hydrogen sulfide may also cause stress corrosion cracking in stainless steel materials. Both elements were present on the crack surface.

Three conditions are necessary for stress corrosion cracking to occur: a susceptible material, a corrosive environment and high tensile stresses, typically high localized stresses. All three elements were present at this location.

The cracking was primarily located 4" to 6" above the water line in the recycled ash water hopper. Stress corrosion cracking will occur at temperatures above 150°F. Appendix A, depicting the temperature gradients of the seal curtain, showed cracking occurring at temperatures ranging from 144° to 156°F. Intermittent wetting and drying conditions will further accelerate the crack progression. The submerged portion of the seal curtain had not illustrated the cracking condition apparent 4" to 6" above the waterline.

The cold forming of the stainless steel sheet will induce cracking due to high localized stresses. Stainless steel sheet is cold worked during the forming operation. Welding will also induce stresses in materials, thus increasing the susceptibility of the material to stress corrosion cracking.

The microstructure depicted intergranular and transgranular cracking is characteristic of stress corrosion cracking. The presence of scale-filled cracks is also indicative of stress corrosion cracking.

The carbon steel header would not be susceptible to chloride or sulfide stress corrosion cracking under these operating conditions. However, pitting in the presence of sulfates and chlorides will occur. In addition, caustic stress corrosion may also occur in the carbon steel materials in the presence of

high concentrations of caustics (sodium hydroxide). The pH recorded in the recycled ash water indicated a potentially caustic environment. Caustic stress corrosion in carbon steel materials typically does not occur at temperatures below about 300°F. Stress relieved vessels typically reduce the susceptibility for caustic stress corrosion cracking to occur. In addition, the insulation and aluminum sheet would provide protection from any contact with the environment.

CONCLUSIONS

The failure of the seal curtain is the result of stress corrosion cracking. The seal curtain was fabricated into a corrugated sheet, thus inducing localized stresses during the cold forming process. The presence of chlorides and high sulfates in the recycled ash water and operating temperatures of approximately 150°F provides the optimum condition for stress corrosion cracking to occur.

As noted, at temperatures below 150°F, cracking had not occurred. Lowering the temperature of exposure would eliminate the potential for cracking. The forming of the stainless steel sheet also induced high localized stresses. If the corrugated sheet is not required by design, flat sheet of solution annealed stainless steel may provide the protection required. Decreasing the localized stresses will lessen the susceptibility of the stainless steel to stress corrosion cracking. Other materials with increased corrosion resistance to stress corrosion cracking

would include Incoloy 800, Inconel 825, Inconel 600 and ferritic stainless steel such as AISI Type 430.

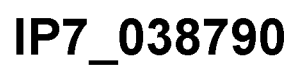


Fig. 1. Engineering drawing illustrating the location of the seal curtain.

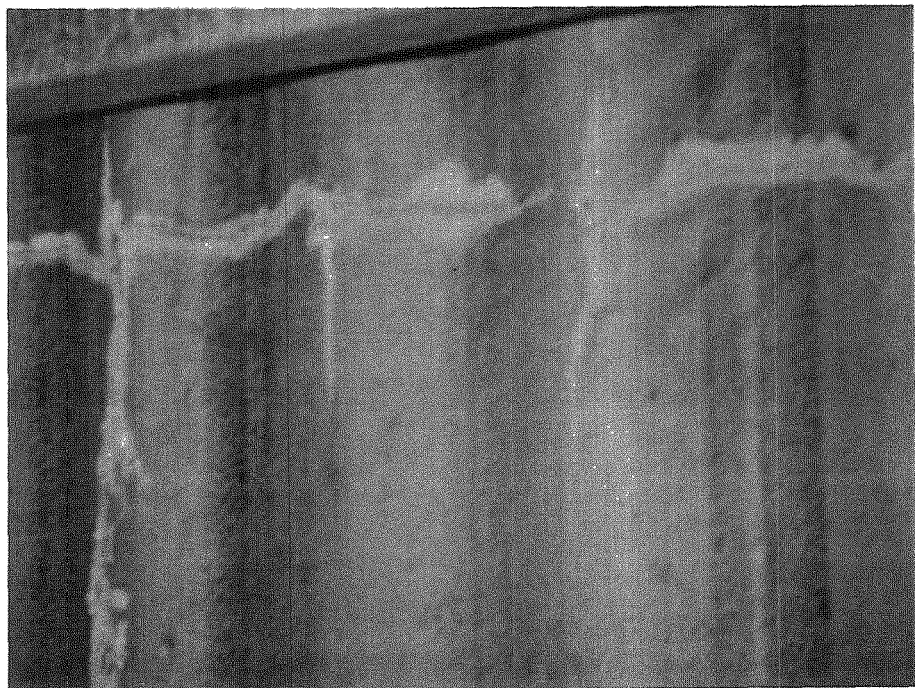
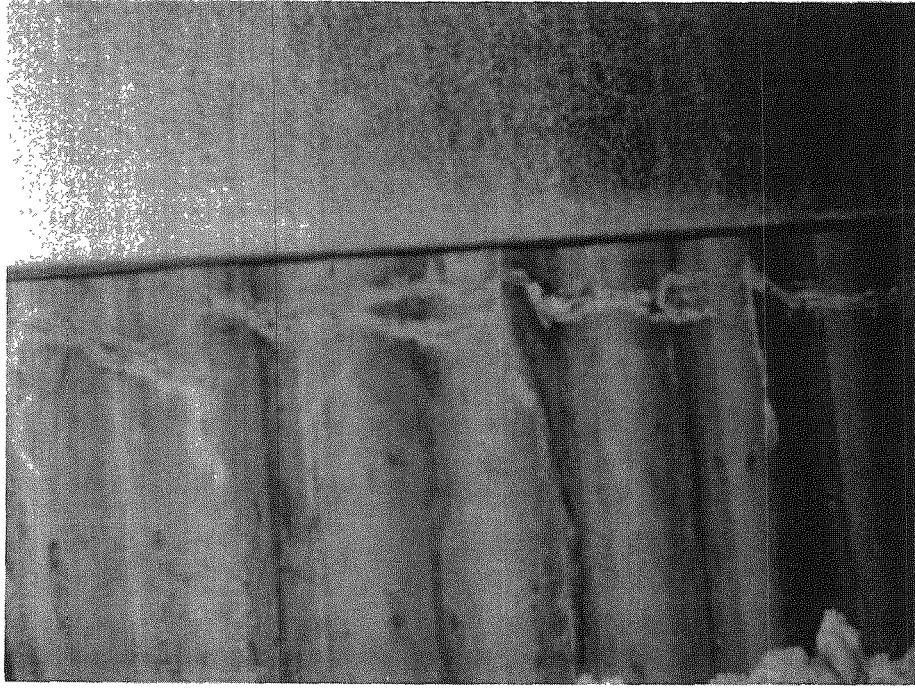


Fig. 2. Overall views of the bottom ash seal curtain cracks (outer surface).

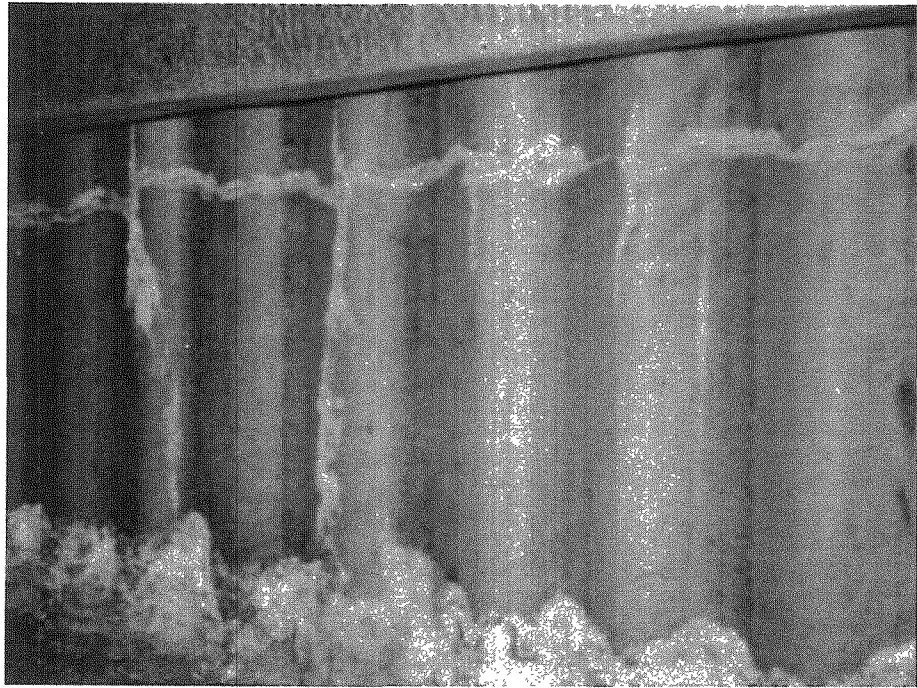
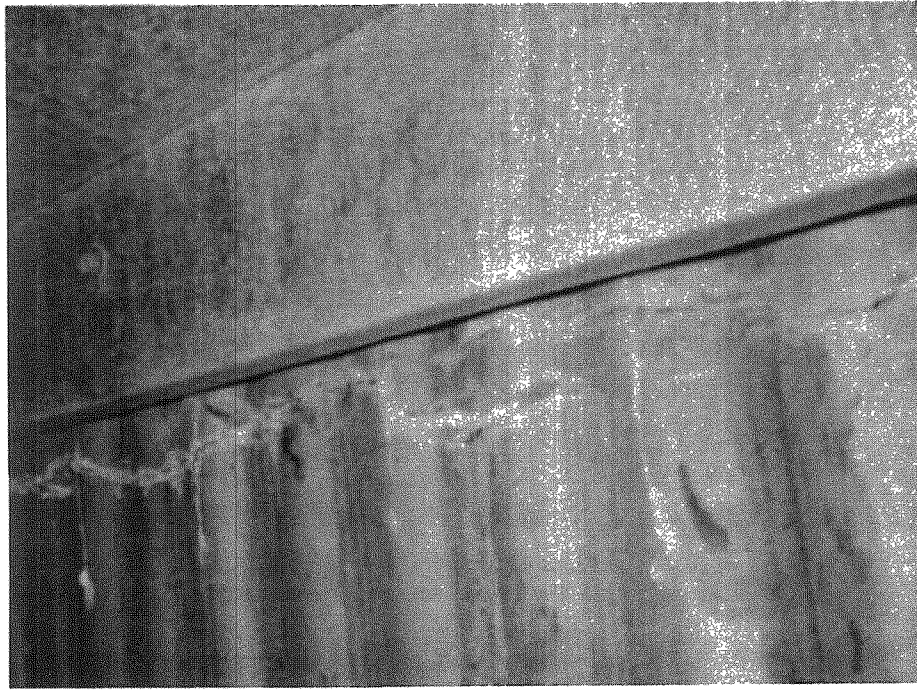


Fig. 3. Additional views of the bottom ash seal curtain cracks (outside surface).

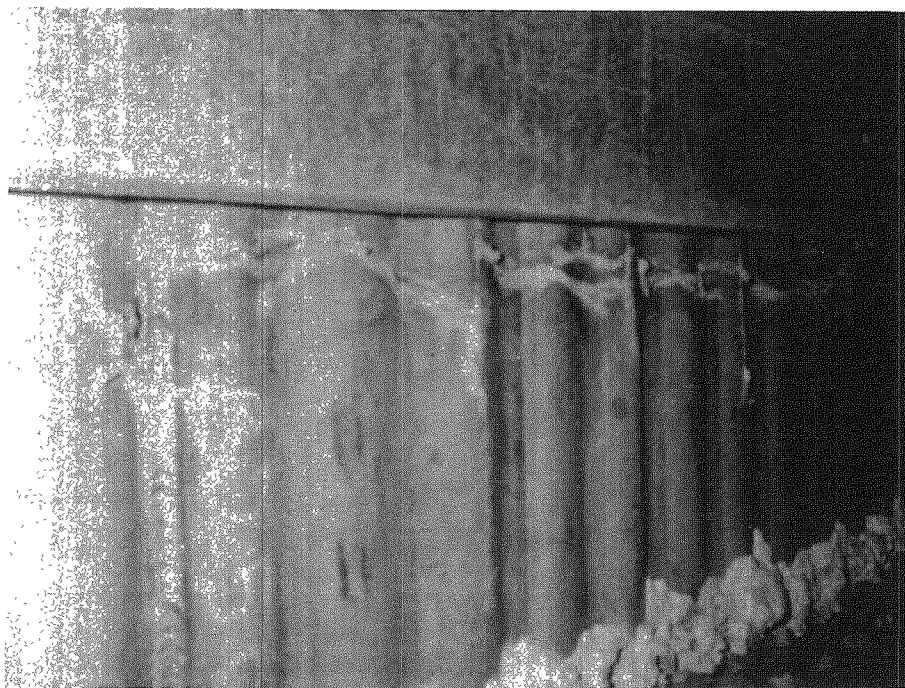
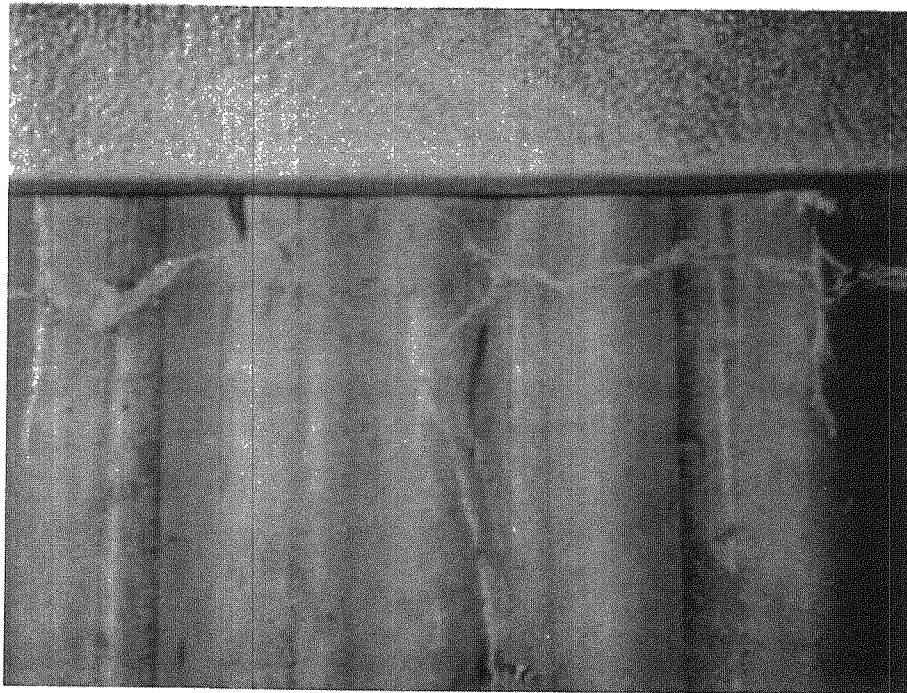


Fig. 4. Additional views of the bottom ash curtain cracks.

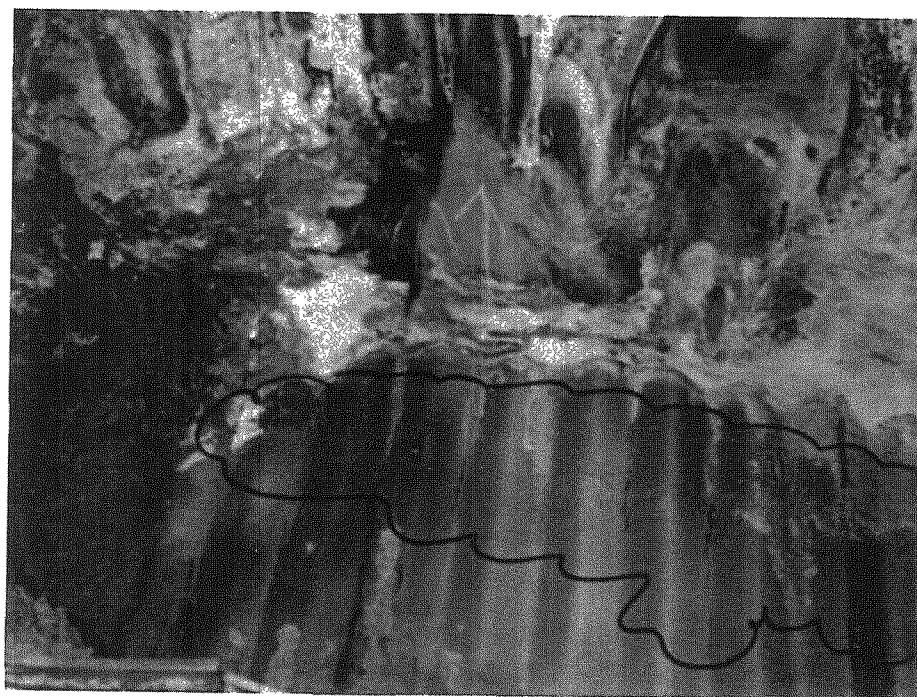
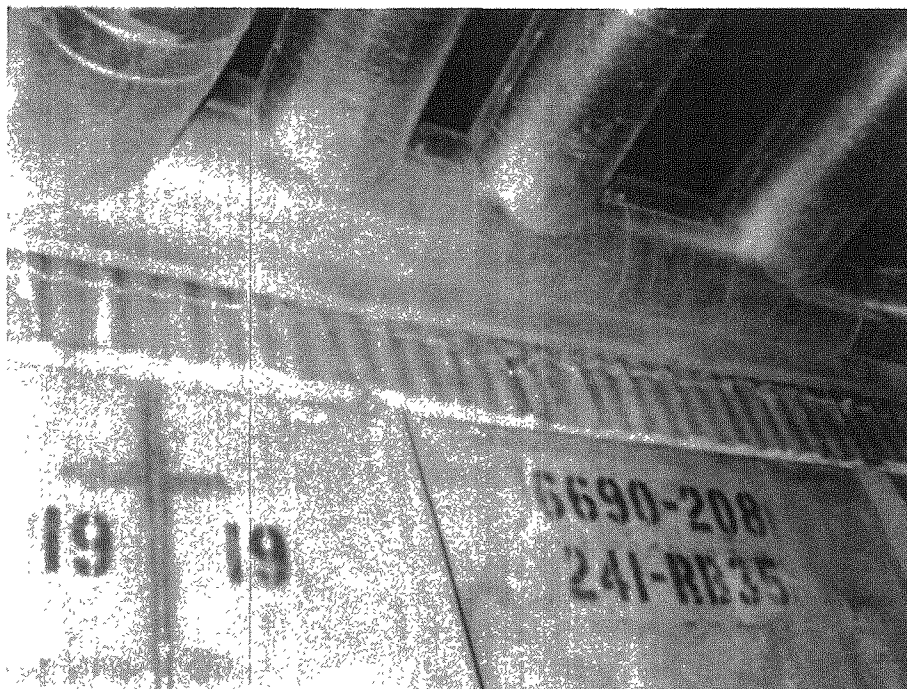
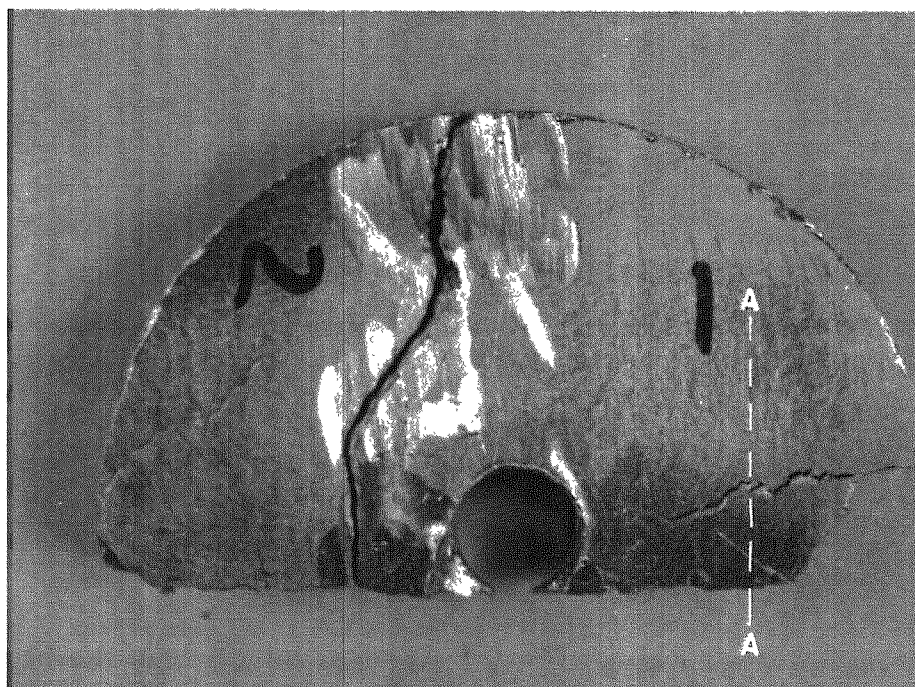
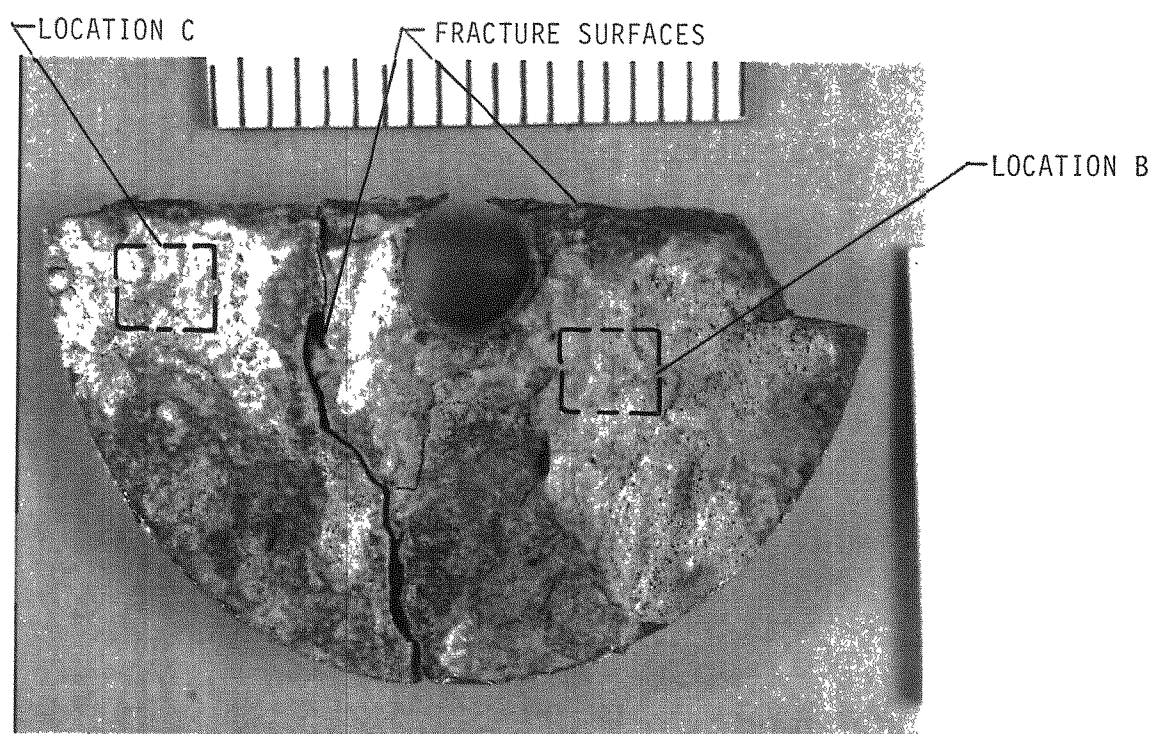


Fig. 5. Comparison of the Unit No. 2 seal curtain crack-
ing (top photograph) and initial stages of crack-
ing observed in Unit No. 2 (bottom photograph).



2 1/2X



2 1/2X

Fig. 6. Overall views of sections received.



3X



3X

Fig. 7. Close-up views of the fracture surfaces.

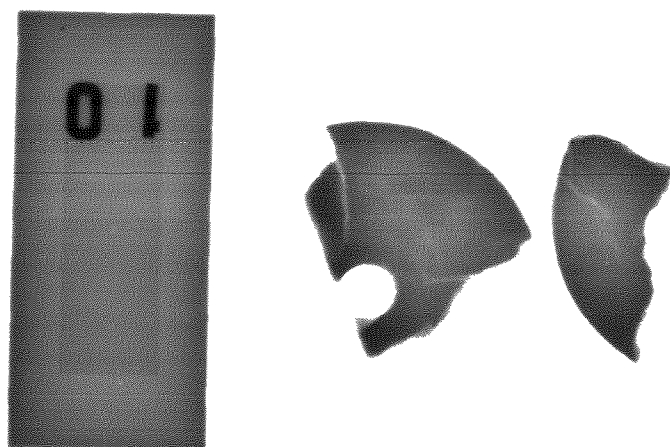
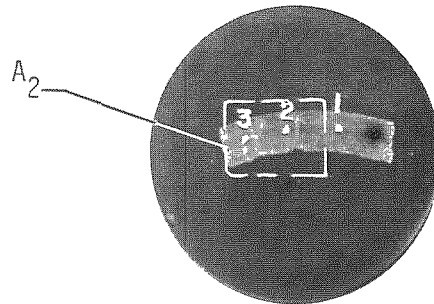


Fig. 8. Photographic print of radiographic film recorded of the sections received.

Rockwell "B" Values

1. 91.8 (201)
2. 89.7 (191)
3. 92.3 (203)



1X

Fig. 9. Overall view of subsegment cut at cross section "A-A". Rockwell "B" hardness determinations are also provided. The corresponding Brinell values are indicated in ().

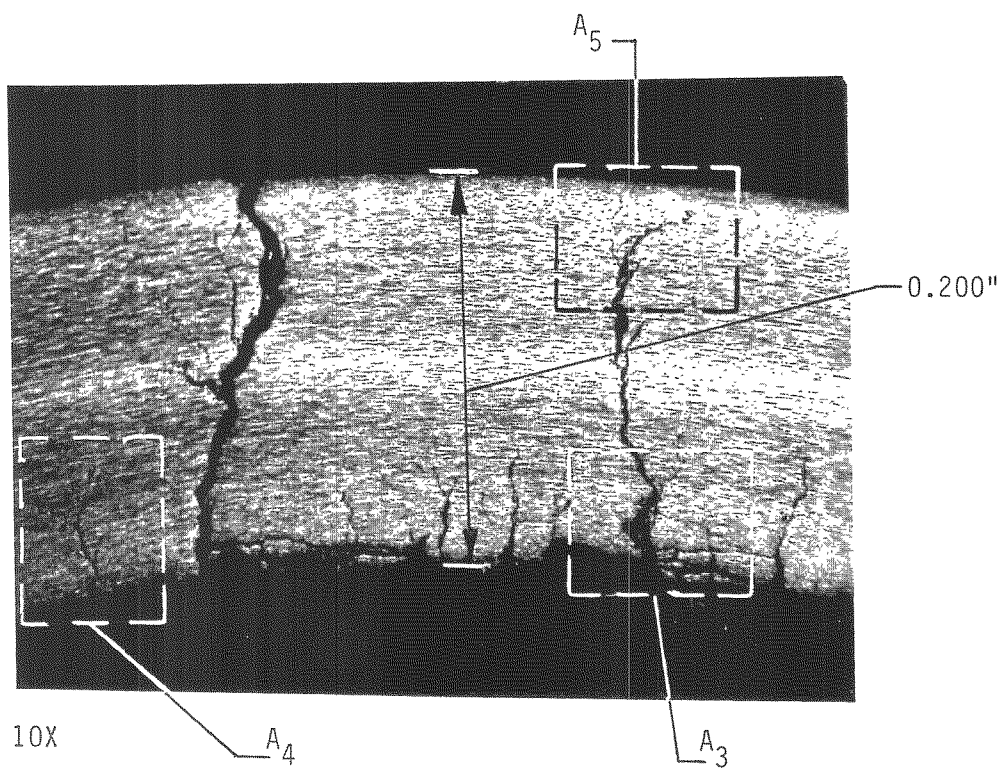
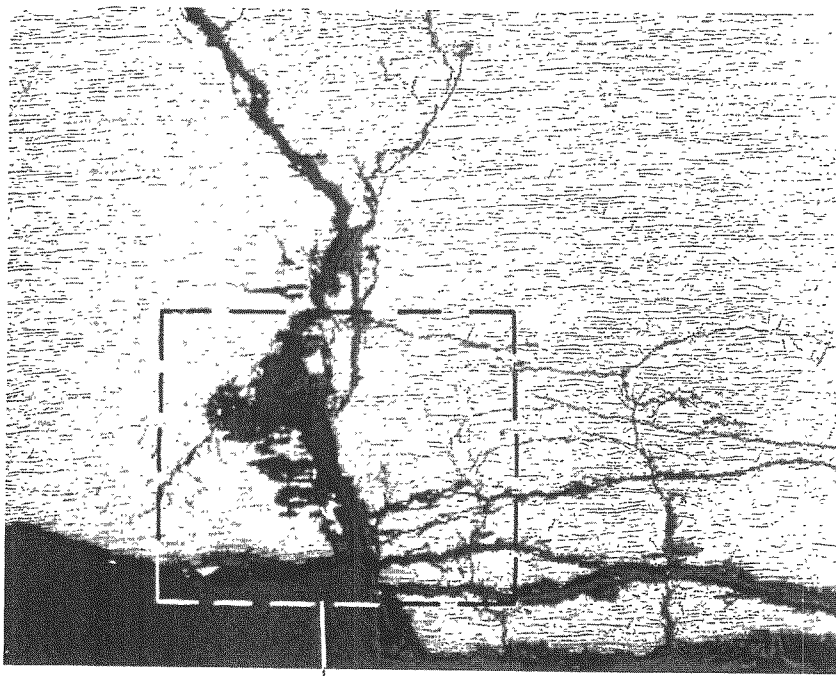


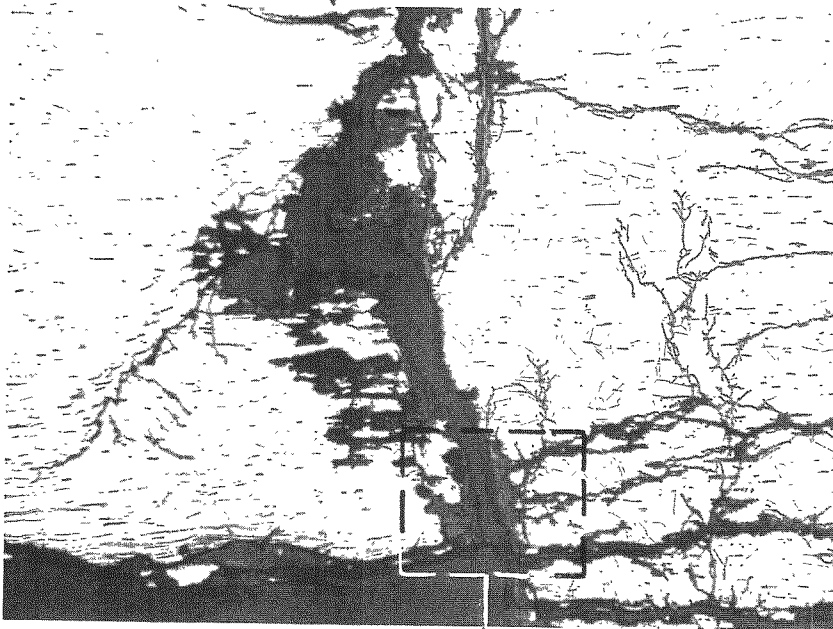
Fig. 10. Photomicrograph at "A₂".

Fig. 11.

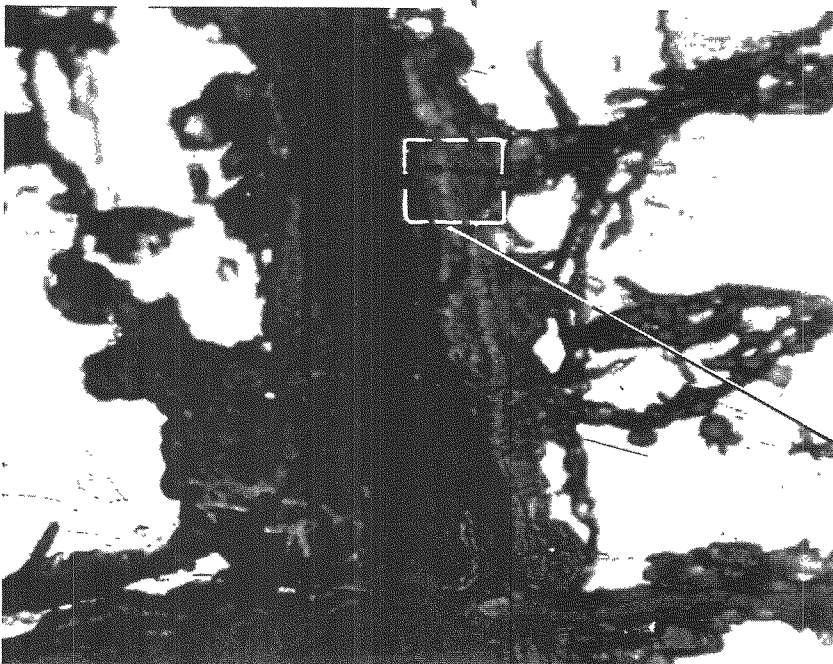
Microstructure at "A₃".



50X

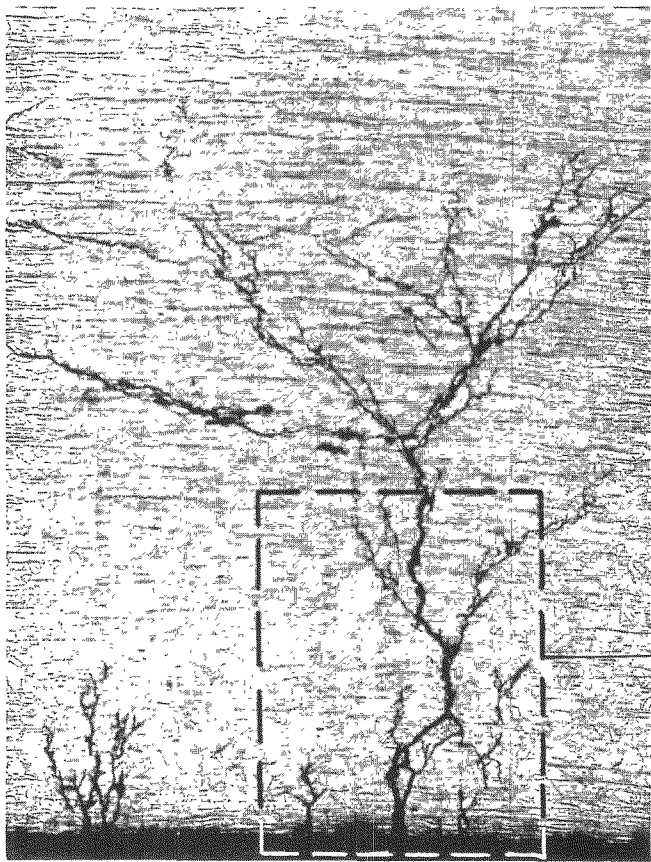


100X

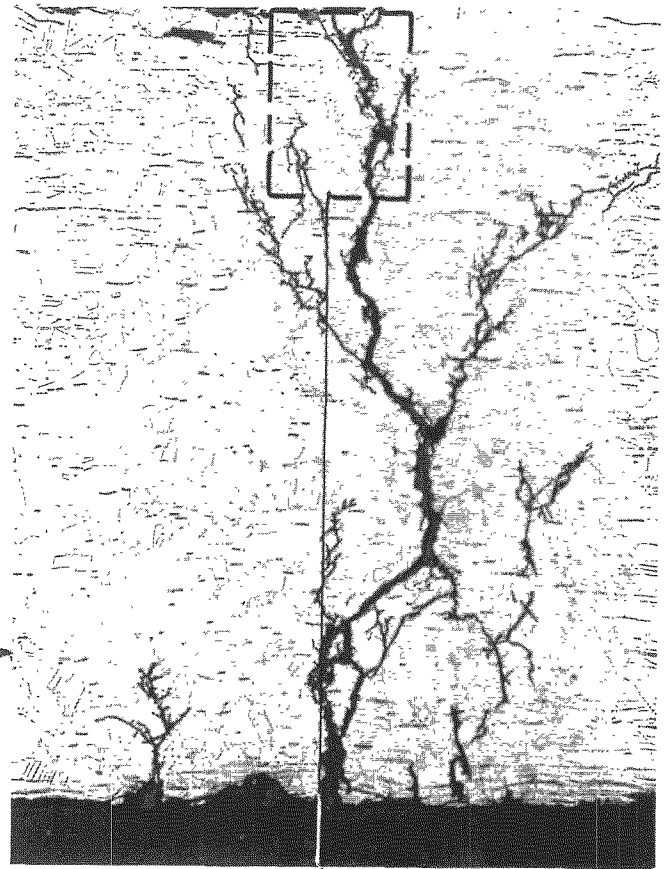


500X

LOCATION F



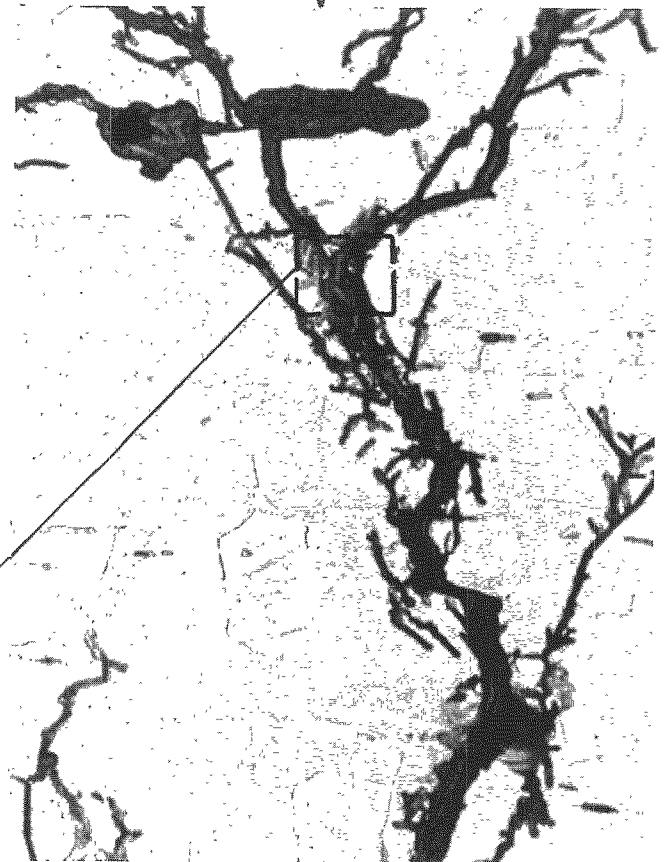
50X



100X

Fig. 12. Microstructure at "A₄".

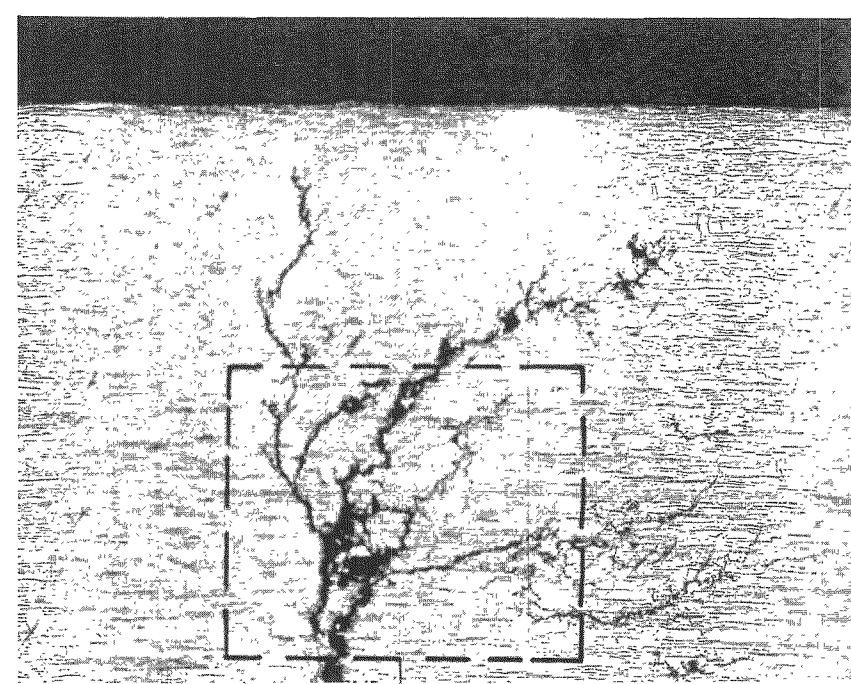
LOCATION G



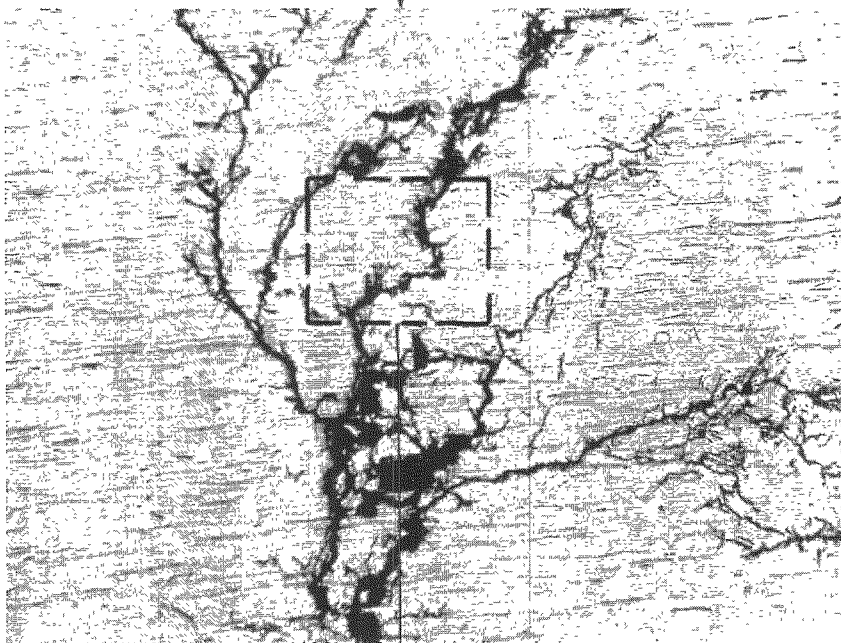
500X

Fig. 13.

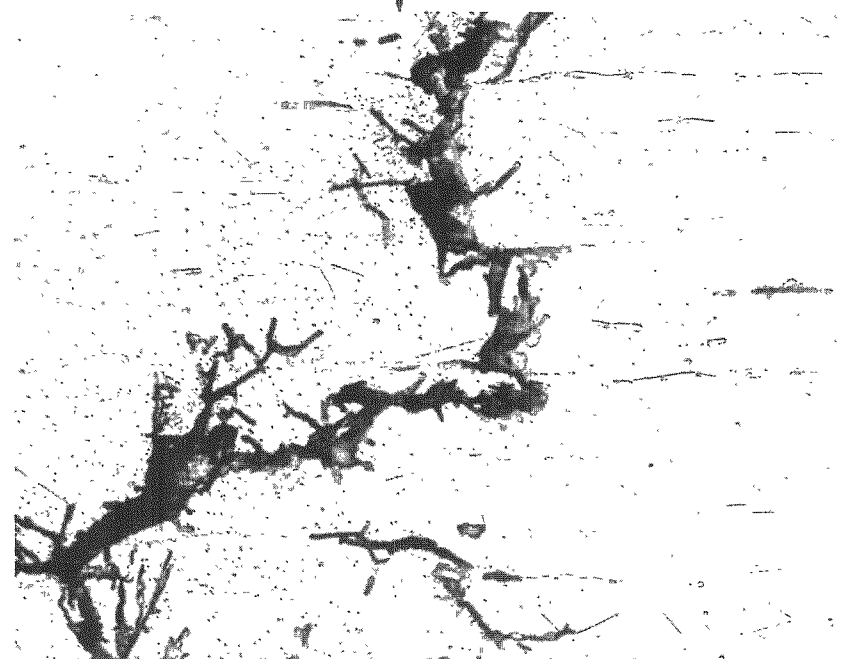
Microstructure at "A₅".



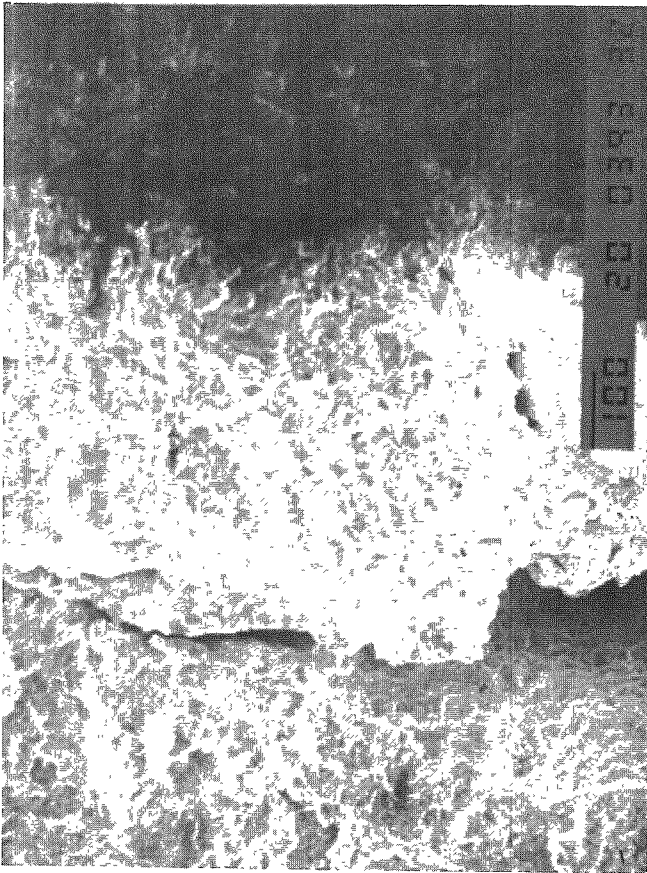
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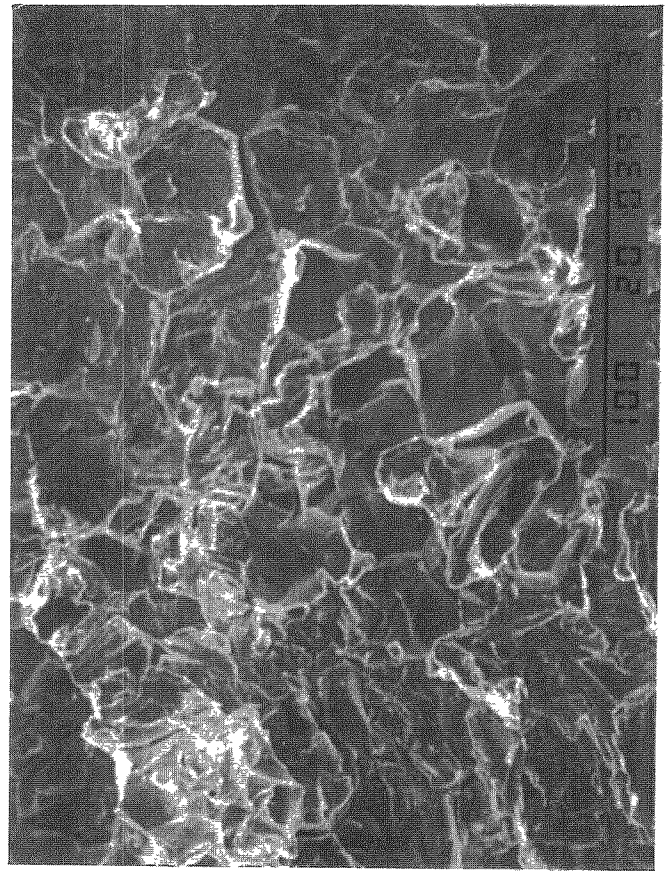
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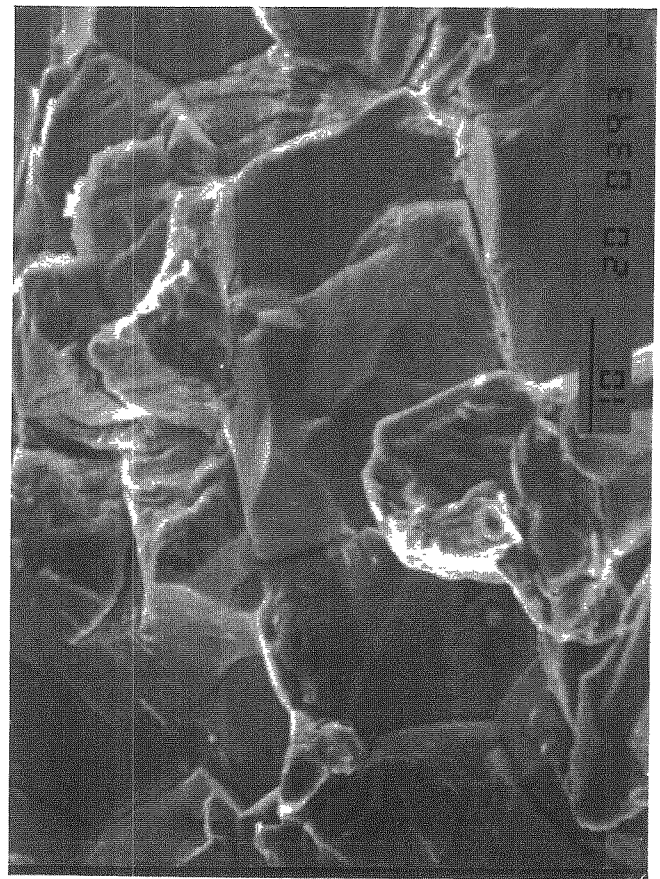


100X



500X

Fig. 14. Scanning Electron Micrographs (SEM) of opened crack surface.



1500X

50

130023 INTERMOUNT #1 ID DEPOSIT 15KV F17

AF5 = 2048 12.240

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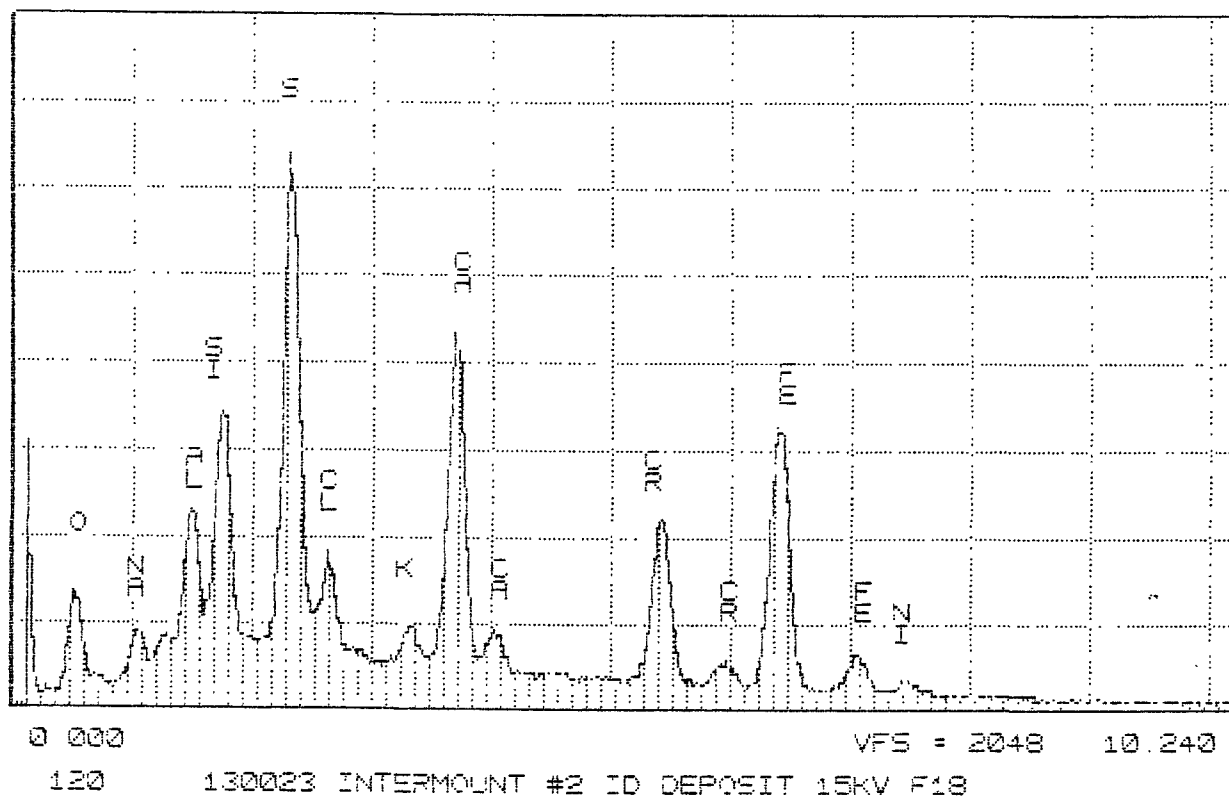


Fig. 16. Energy Dispersive Spectral (EDS) plot recorded of location C.

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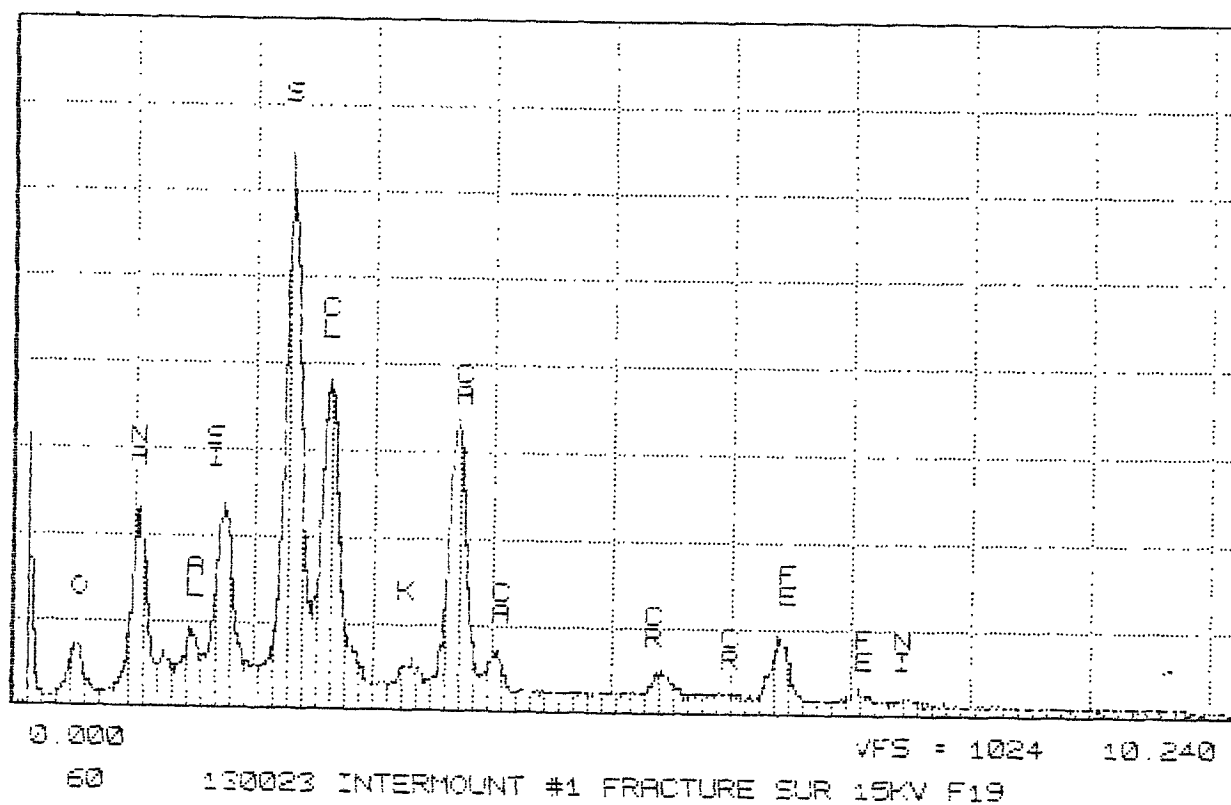


Fig. 17. Energy Dispersive Spectral (EDS) plot recorded of location D.

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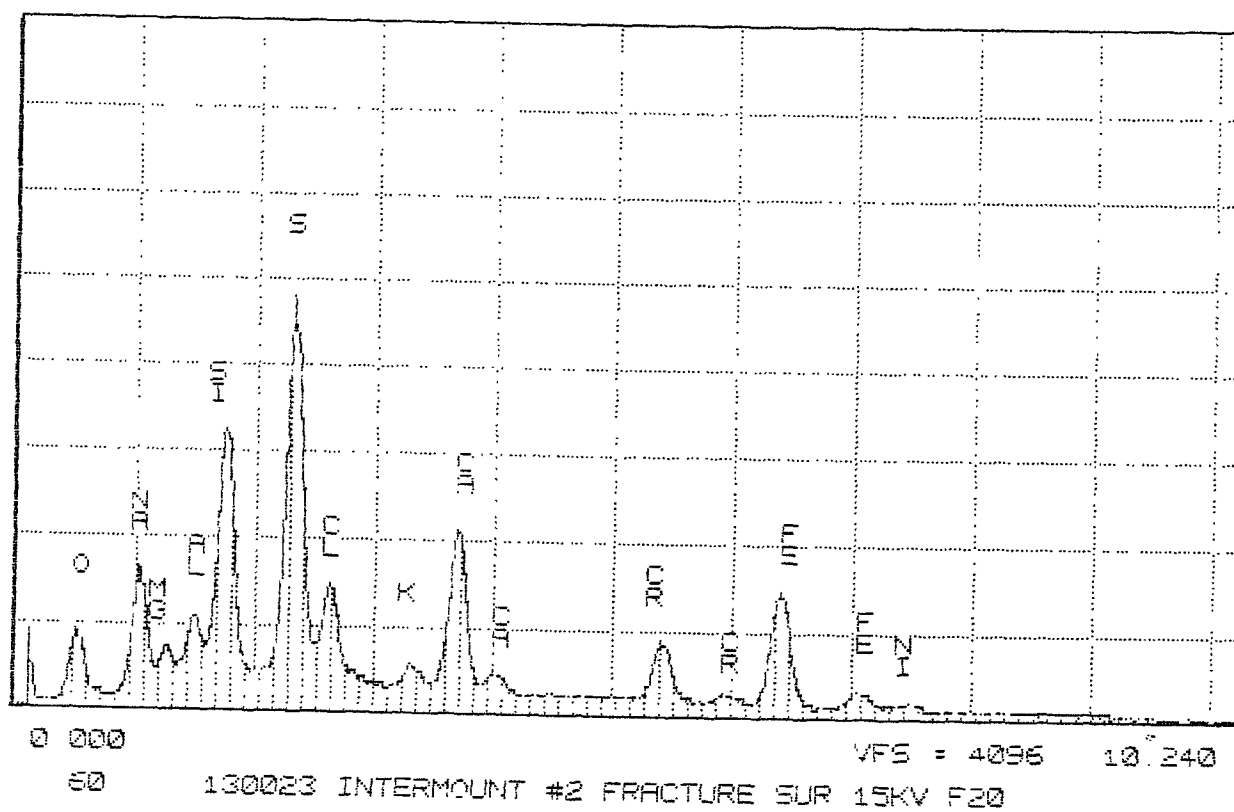


Fig. 18. Energy Dispersive Spectral (EDS) plot recorded of location E.

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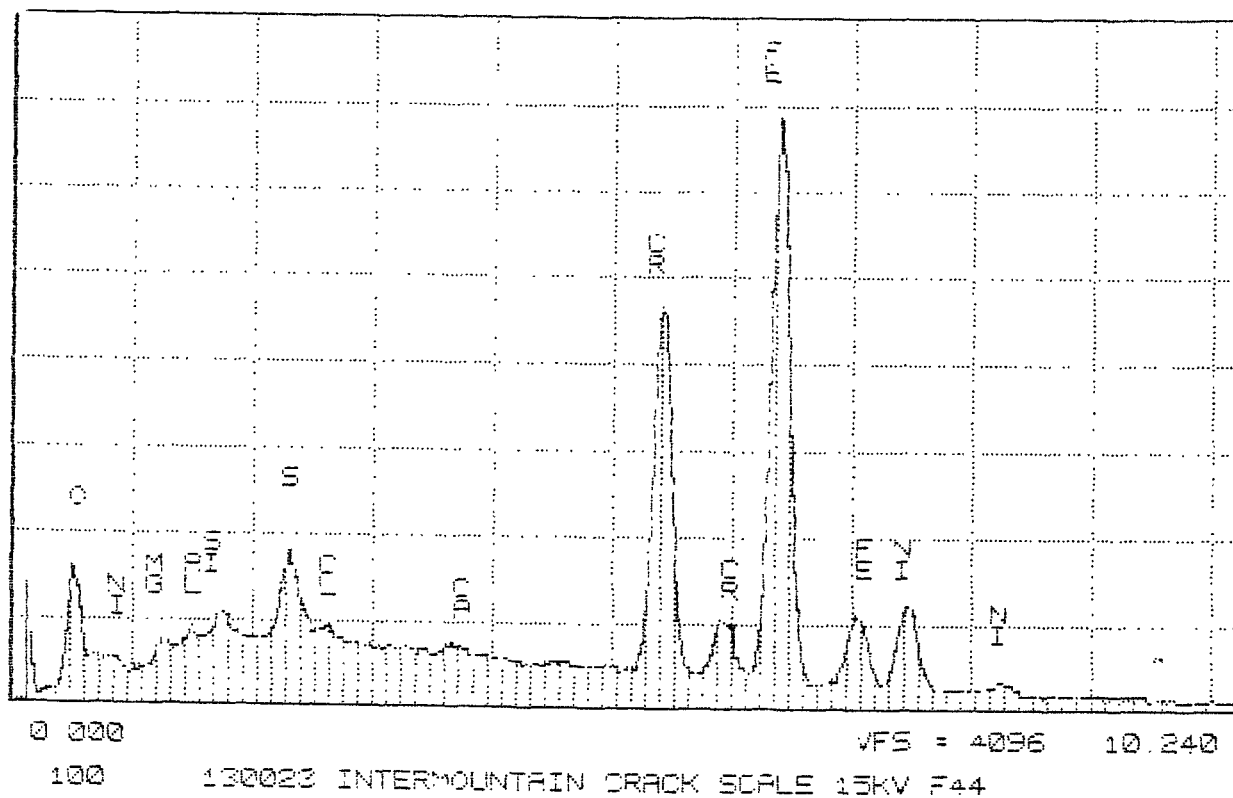


Fig. 19. Energy Dispersive Spectral (EDS) plot recorded of location F.

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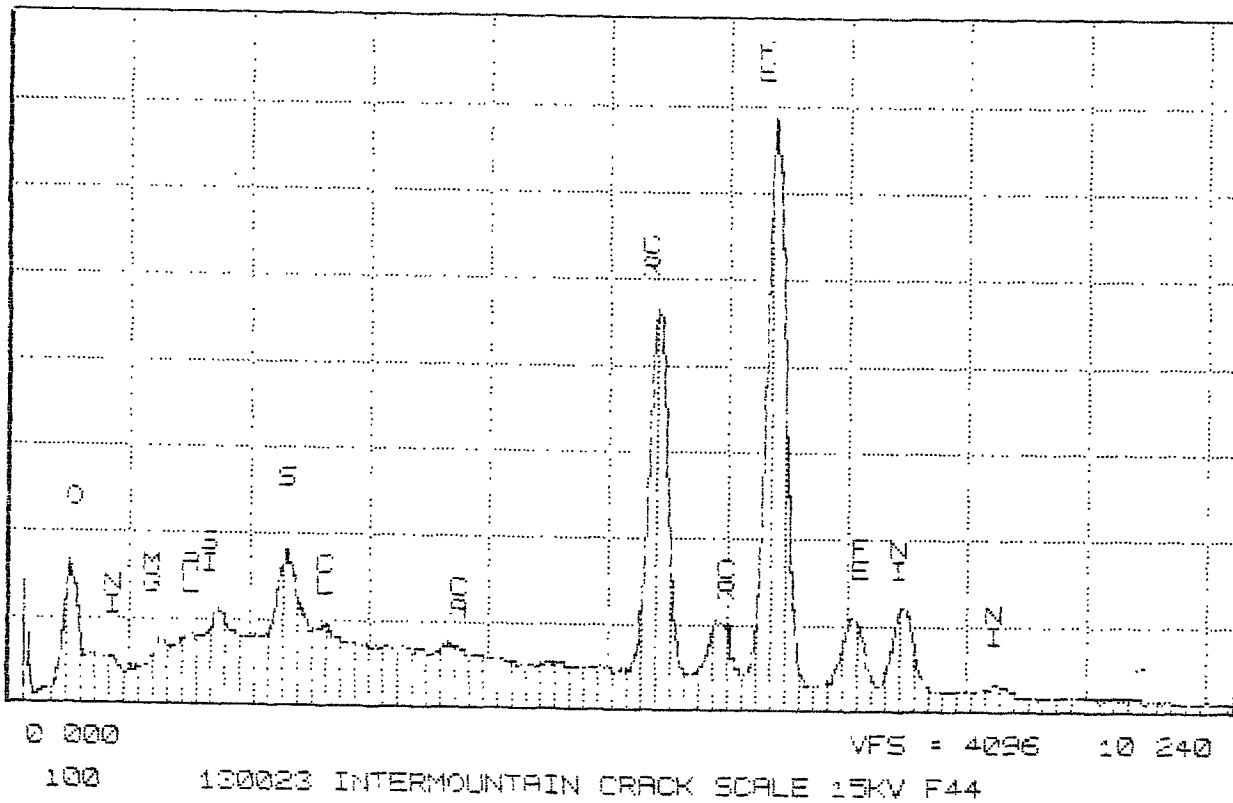
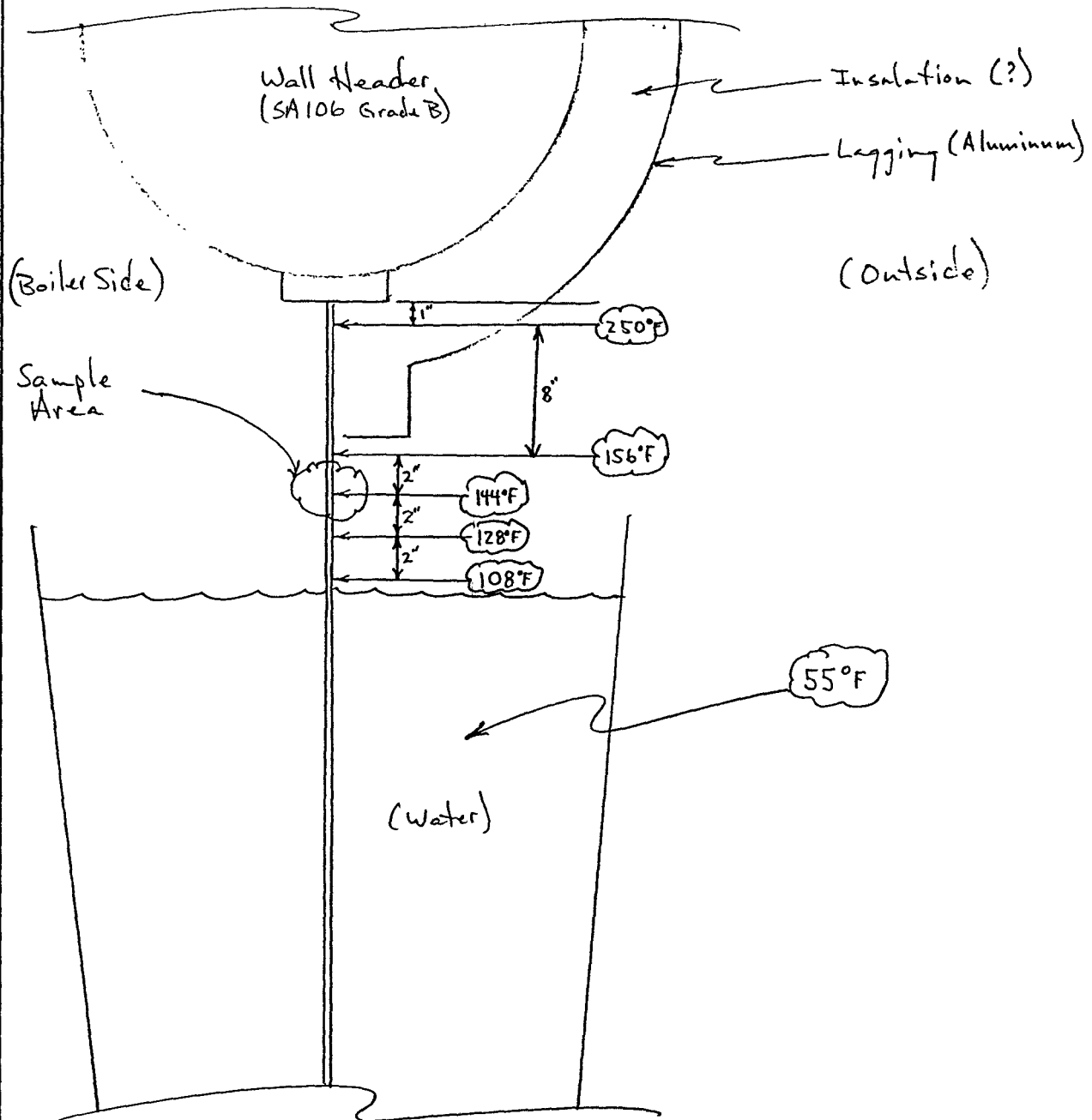


Fig. 20. Energy Dispersive Spectral (EDS) plot recorded of location G.

BOTTOM ASH SEAL CURTAIN
TEMPERATURE GRADIENTS

Bottom Ash Seal Curtain Temperature Gradients.

2/1/93



RECYCLED ASH WATER
CHEMICAL ANALYSIS

Aug 11, 1992 00:00

pH: 10.9

Temp. 23.9

Cond. 6140

Total Suspended Solids SM209C
Total Dissolved Solids SM209B
pH SM423
Alkalinity (as CaCO3) EPA 310.1
Fluoride EPA 352.1
Nitrate EPA 352.1
Sulfate EPA 375.3
Conductivity SM 205
Chloride SM 407B
Carbonate EPA 310.1
Bicarbonate EPA 310.1
Mercury EPA 245.1
Arsenic
Boron
Cadmium
Calcium
Chromium
Copper
Iron
Lead
Magnesium
Manganese
Nickel
Potassium
Selenium
Silica
Sodium
Strontium
Zinc

		<i>Test Started</i>		
10 mg/L	Aug 14, 1992	15:00	MDL: 1	
4480 mg/L	Aug 17, 1992	08:00	MDL: 1	
10.88 SU	Aug 13, 1992	14:30	MDL: 0	
89 mg/L	Aug 14, 1992	10:00	MDL: 1	
0.6 mg/L	Aug 17, 1992	08:15	MDL: 0.001	
0.25 mg/L	Aug 12, 1992	15:00	MDL: 0.001	
3,129 mg/L	Aug 15, 1992	08:45	MDL: 1	
5970 µmhos/cm	Aug 13, 1992	14:30	MDL: 1	
827 mg/L	Aug 20, 1992	15:00	MDL: 1	
11 mg/L	Aug 14, 1992	10:00	MDL: 1	
77 mg/L	Aug 14, 1992	10:00	MDL: 1	
< 0.0005 mg/L	Aug 13, 1992	07:40	MDL: 0.0005	
< 0 mg/L	Aug 13, 1992	07:40	MDL: 0	
.008 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .01 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .005 mg/L	Aug 13, 1992	07:40	MDL: 0	
705 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .050 mg/L	Aug 13, 1992	07:40	MDL: 0	
.075 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .100 mg/L	Aug 13, 1992	07:40	MDL: 0	
34.1 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .030 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .040 mg/L	Aug 13, 1992	07:40	MDL: 0	
15.5 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .002 mg/L	Aug 13, 1992	07:40	MDL: 0	
14.9 mg/L	Aug 13, 1992	07:40	MDL: 0	
964 mg/L	Aug 13, 1992	07:40	MDL: 0	
5.74 mg/L	Aug 13, 1992	07:40	MDL: 0	
< .005 mg/L	Aug 13, 1992	07:40	MDL: 0	

Approved by:

D. de la Cruz

Page 1

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